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Evaluation of SeaWiFS chlorophyll algorithms in the Southwestern Atlantic and Southern Oceans

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Abstract

Bio-optical measurements of spectral upwelling radiance and surface chlorophyll-*a* concentration have been conducted during 15 cruises between 1995 and 2004. The bio-optical data were divided into two sub-sets: the Southwestern Atlantic Ocean (SwAO), comprising a variety of biogeochemical provinces, from the oligotrophic waters in the South Atlantic gyre to the coastal waters influenced by La Plata River and Patos Lagoon discharge, and the Southern Ocean (SO) data set, comprising sampling stations south of the mean position of the Polar Front, with most stations being located in the vicinity of the Antarctic Peninsula. We derived regional chlorophyll algorithms for both regions and comparisons were made with the NASA's OC4v4 (operational algorithm) and OC2v4. For the Southwestern Atlantic region, the NASA OC4v4 algorithm presented a reasonable performance (r^2=0.87, rmse-L=0.475, N=136) as compared to the revised algorithm for SwAO data (r^2=0.89, rmse-L=0.426, N=136). A few stations under strong river plume influence were not considered in the analyses. These were detected by a higher reflectance at 670 nm, at low in situ chlorophyll concentration (<2 mg m^{-3}). These results show that empirical algorithms applied to in-situ radiance data have a limited ability to extract accurate chlorophyll estimates below a 30% uncertainty level. For Southern Ocean stations, a 2-band linear-type model was generated (r^2=0.64, rmse-L=0.347, N=77), which significantly improved the bias (6.4%) as compared to NASA's OC4v4 algorithm (bias=−21.7%). An evaluation of some published high-latitude algorithms on our data set has shown a better performance by taxon-specific models, even from distant regions. A validation experiment of the normalized spectral water-leaving radiances and chlorophyll-*a* SeaWiFS products was also conducted using the FURG-SwAO/SO data set, through a match-up exercise. Despite the relatively low number of pairs of radiometric measurements, SeaWiFS estimations compare well with in situ data (0.77<r^2<0.98, N=21), although the satellite estimate show a marked bias (−35.6%) in the blue band nL_w (412). Regarding the chlorophyll-*a* concentration, an overall agreement was observed (r^2=0.77, rmse-L=0.66, N=28), with a mean absolute percentage difference of 66%, which is above the goal generally accepted of 35% for satellite ocean color chlorophyll estimates. For the studied Southern Ocean area (mainly the Bransfield Strait), NASA's OC4v4 algorithm systematically underestimates chlorophyll above 0.2 mg m^{-3}, as previously demonstrated by other researchers.

Keywords: Ocean color; SeaWiFS; Chlorophyll; Southwestern Atlantic Ocean; Southern Ocean

1. Introduction

Remote sensing techniques have been successfully used to provide a synoptic coverage of surface patterns of phytoplankton biomass distribution at a global scale. Several algorithm types have been proposed for retrieving chlorophyll-*a* from ocean color data, including empirical (e.g. Gordon et al., 1983) and semi-analytical (e.g. Maritorena et al., 2002) models. O'Reilly et al. (2000) presented an update of NASA's OC2 and OC4 SeaWiFS algorithms, based on a large in situ data set, including measurements in oligotrophic and eutrophic waters around the world oceans. Over the past few years, there have been increasing efforts to gather in situ spectral optical properties data for remote sensing data validation (Hooker & McClain, 2000). Recently, regions like the Mediterranean Sea (D'Ortenzio et al., 2002) and high latitude areas in the North Atlantic (Cota et al., 2003; Stramska et al., 2003) have been sampled for algorithm development and evaluation.

Bio-optical properties of seawater in the South Atlantic Ocean are poorly known, despite the works of some investigators (Aiken & Hooker, 1997; Omachi & Garcia, 2000). A significant contribution has been made during the Atlantic Meridional Transect (AMT) program (Aiken et al., 2000). Data from this program have been used to examine and characterize the properties of the biogeochemical

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provinces and their boundaries over the Atlantic Ocean (Hooker et al., 2000). A more detailed classification of biogeographical regions was generated for the Southwestern Atlantic region using CZCS and SeaWiFS derived pigment variability (Gonzalez-Silvera et al., 2004). A recent report, focused on the distribution of phytoplankton pigments and bio-optical properties of a section of the AMT data from the South Atlantic Ocean (0–40°S), is given by Signorini et al. (2003).

In the Southwestern Atlantic, the presence of La Plata River mouth (at 35°S), and to a lesser extent the Patos Lagoon mouth (at 32°S), originate a low salinity plume along the shelf that can extend northward up to approximately 28°S during the austral winter (Piola et al., 2000). In some cases, coastal waters influenced by the plume may show a sharp increase in chlorophyll-*a* concentration (Negri et al., 1992), particularly in El Niño years, when high chlorophyll events (>15 mg m^{-3}) are related to anomalous large freshwater outflow (Ciotti et al., 1995). Concerning ocean color pigment retrievals, the presence of these plumes cause the optical properties of the water in the region to be affected by both inorganic and organic matter from the continental runoff. Indeed, it has been shown that SeaWiFS-derived chlorophyll values can be highly overestimated in coastal waters influenced by the La Plata River plume (Armstrong et al., 2004). Based on SeaWiFS chlorophyll time-series analyses, Garcia et al. (2004) reported that near La Plata River (where values are probably contaminated by plume waters) chlorophyll variability present no detectable seasonal cycle, as opposed to the adjacent areas, where a marked annual cycle is observed.

In the Southern Ocean, in situ sampling is limited by severe weather conditions and isolation from land based institutions. These difficulties have restricted the studies predominantly to areas close to the Antarctic coastal zone. Data from investigations in the western Antarctic Peninsula have shown that NASA's algorithms underestimate pigment concentration in the area (Dierssen & Smith, 2000; Mitchell & Holm-Hansen, 1991; Mitchell et al., 2001). Both low concentrations of detritus and large pigment packaging of the dominant phytoplankton species have been suggested as causes for the failure of global algorithms in the region (Mitchell & Holm-Hansen, 1991). Mitchell (1992) has already suggested the need for a specific ocean color pigment algorithm for polar regions. In the Australian sector of the Southern Ocean, Clementson et al. (2001) have also found that the NASA OC4v4 algorithm generally underestimates chlorophyll-*a* concentration but overestimates in low pigment (<0.15 mg m^{-3}) areas. On the other hand, in the southwestern Ross Sea, the bio-optical relationship is strongly dependent on the phytoplankton species present and in some cases they resemble those of temperate waters (Arrigo et al., 1998).

The main goal of this work is to present an independent bio-optical data set consisting of spectral upwelling radiance measurements and chlorophyll-*a* concentration in the Southwestern Atlantic and adjacent sectors of the Southern Ocean, collected during 15 cruises between 1995 and 2004. These regions have been considered relevant in terms of the global ocean carbon cycle, as important CO_2 sink areas (Feely et al., 2001; Sarmiento & Sundquist, 1992; Takahashi et al., 1997). The Southwestern Atlantic and Southern Oceans data set of Federal University of Rio Grande (FURG-SwA/SO) are used to generate regional algorithms and compare their performances with NASA's SeaWiFS operational algorithms. We also compare our bio-optical data to both other data sets from the Atlantic and Antarctic waters and to SeaWiFS-retrieved values (match-up analyses).

5. Conclusions

Bio-optical properties have been measured in the surface waters in the Southwestern Atlantic and Southern Ocean (mostly Bransfield Strait) for chlorophyll algorithm generation and validation of remote sensing oceanic properties provided by ocean color sensors. The bio-optical data set comprises several bio-geographic provinces, ranging from oligotrophic waters in the South Atlantic tropical gyre to highly productive coastal waters influenced by the La Plata River and Patos Lagoon.

Our analysis show that the NASA's OC4v4 algorithm for extracting chlorophyll-*a* data in the Southwestern Atlantic would result in an error margin of at least 42% (or a rmse-L of 47%) in waters without strong influence of continental discharge (from La Plata River or Patos Lagoon). Our derived algorithm for this region improves the error margin to some extent (32% error margin or rmse-L of 43%), but significantly reduces bias. In coastal waters affected by river runoff, the OC4v4 algorithm highly overestimates chlorophyll values. These waters have been masked in our work using $R_{rs}(670)>0.0012$ sr^{-1} combined with in situ chlorophyll values less than 2 mg m^{-3} in regions under potential freshwater plume influence.

In the Southern Ocean, comprising mainly the Bransfield Strait, the NASA OC4v4 algorithm underestimates pigment concentration but not to the same magnitude as previously reported (Dierssen and Smith, 2000; Mitchell & Holm-Hansen, 1991). A linear relationship has been proposed between R_{555}^{490} and chlorophyll ranges from 0.1 to 1 mg m^{-3}, which yields a significant improvement in bias, as compared with both NASA's OC4v4 and OC2v4. An evaluation of other high-latitude algorithms from the literature showed variable performances when applied to our data. The best adjustment (following our linear model) was found for the Ross Sea, Prymnesiophyte-specific algorithm (Arrigo et al., 1998).

The spectral water-leaving radiance and chlorophyll-*a* concentration derived from SeaWiFS were compared with FURG-SwAO/SO bio-optical measurements through a match-up procedure. There is a good agreement between in-situ and sensor-derived optical data (APD between 10.8% and 41.9%; rmse between 0.04 and 0.20). For chlorophyll match-ups, the concentration estimated by SeaWiFS imagery (OC4v4 algorithm) show a positive bias of 32% and values are comparable with in-situ data, within a 66% error, which is above the accuracy goal of 35% for satellite-retrieved chlorophyll estimates.